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Abstract

Mangroves are part of rich ecosystems providing a variety of environmental goods and services. Underestimation of their value and of the impacts of human activities is a major factor contributing to the widespread loss and degradation of ecosystems. Economists frequently receive the blame for such environmental ills, but it may also be argued that ecologists inadequately communicate their knowledge to decision makers and therefore have limited influence. This article links information supplied by ecologists to the information required for effective and efficient mangrove management. A key problem which ecologists face is the high degree of interconnectedness within and between ecosystems. This makes it difficult to predict what is going to happen let alone understand what is going on. The concept of 'environmental function' is used in combination with systems diagrams to address this problem. System diagrams are used to identify and assess goods and services produced by the system under different management regimes. These goods and services are then valued to enable assessment of the economic efficiency of the management regimes.

Abrégé

Les mangroves font partie de riches écosystèmes fournissant toute une variété de biens et services environnementaux. La sous-estimation de leur valeur et de l'impact des activités humaines à leur égard est un facteur essentiel de la perte et de la dégradation universelle des écosystèmes. C'est aux économistes qu'on fait souvent porter le blâme pour ces difficultés écologiques, mais on peut aussi estimer que les écologistes communiquent bien mal leurs connaissances aux décideurs et n'exercent donc qu'une influence limitée. Ce texte établit un lien entre les informations fournies par les écologistes et celles requises pour une gestion efficace des mangroves. Un des prolèmes-clés recontrés par les écologistes tient au degré élevé d'interconnexion existant au sein des écosystèmes et entre eux, ce qui rend difficile toute prévision de ce qui va se passer, voire même la compréhension des phénomènes en cours. Le concept de 'fonction environnementale' est employé de concert avec des graphiques systémiques afin de traiter ce problème. Les graphiques systémiques servent à identifier et à évaluer les biens et services produits par un écosystème selon différents régimes de gestion. Ces biens et services sont ensuite évalués de manière à faciliter l'estimation de l'efficacité économique de chaque régime de gestion.

Resumen

Los manglares hacen parte de ricos ecosistemas que ofrecen una gran variedad de bienes y servicios ambientales. El subestimar su valor y los impactos de las actividades humanas es un factor importante que contribuye a la degradación de los ecosistemas. Ocurre con frecuencia que a los economistas se les culpa por estos problemas ambientales y sin embargo es posible que el hecho de que la influencia de los ecologistas sea limitada se deba a la falta de comunicación entre éstos y quienes toman las decisiones. Este artículo busca establecer vínculos entre la información suministrada por ecologistas y la requerida para una efectiva y eficiente gestión de los manglares. Un problema central que deben enfrentar los ecologistas es el del alto grado de interconexión que existe tanto en el interior de los ecosistemas como entre ellos. Esto no sólo dificulta la predicción de lo que pueda ocurrir sino también la comprensión de lo que está sucediendo. Con relación a este problema en esta monografía se ha usado el concepto de "función ambiental" en combinación con diagramas de sistemas. Estos se usan para identificar y evaluar los bienes y servicios producidos por ecosistemas bajo diversos esquemas de gestión. Para facilitar una evaluación de la eficiencia económica de los esquemas de gestión a estos bienes y servicios se les asigna un valor económico.

Acknowledgements

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Introduction

Mangroves are salt-tolerant trees or shrubs found along low-energy, tidal shorelines between latitudes in tropical and subtropical areas (approximately between 30°N and 30°S). They colonise newly formed tidal flats in the wind and wave shadows of promontories and islands, and behind wave-absorbing sand bars and seagrass beds (Carter, 1988). As much as 75 percent of low-lying tropical coastlines with freshwater drainage support mangrove ecosystems (WRI and IUCN, 1986). Mangroves provide the basis for complex and extensive ecosystems at the interface of terrestrial, freshwater and marine ecosystems (eg, Mann, 1982; Carter, 1988; Robertson and Alongi, 1992).

Mangroves are part of rich ecosystems providing a variety of environmental goods and services. In traditional economies the exploitation of mangrove resources is usually not intensive and settlement is quite sparse. In South East Asia this has been attributed to the scarcity of freshwater for domestic use and the unsuitability of mangrove soils for long-term agricultural use. Recently exploitation of mangrove forests has intensified as traditional economies become increasingly market-integrated and modernised. The building of roads, provision of amenities in these areas, and improvements in technology have provided the impetus. As a result of this transition in use of mangrove forests, mangrove cover in the Philippines has reduced from it original 288,035 ha. in 1970 to 123,400 ha. by 1993.

The widespread loss and degradation of mangroves, as well as other ecosystems, may be largely attributed to an underestimation of their value together with the impact of human activities. Economists frequently receive the blame for such environmental ills. However, it may also be argued that ecologists inadequately communicate their knowledge to decision makers and therefore have limited influence. This paper links information supplied by ecologists to the information required for effective and efficient mangrove management.

Ecologists face two difficulties. The first is that an anthropocentric viewpoint is often seen as incompatible with the study of ecology. Consideration of human activities tends to be 'added-on', much as the environment is 'added-on' to economics. The second is the high degree of interconnectedness within and between ecosystems. This makes it difficult to predict what is going to happen let alone understand what is going on. These two aspects are addressed in this paper through the concept of 'environmental function' used in combination with systems diagrams. The result is qualitative information on the direction and desirability of ecosystem changes under alternative management regimes.

This paper aims to demonstrate the use of environmental functions to evaluate management strategies for the Pagbilao mangrove forest. It presents results from the project "Economic valuation of mangrove-fish pond interactions".

The structure of this paper is as follows.

- Description of the study site
- Specification of the environmental functions
- Description of feedbacks and linkages using systems diagrams to identify and value goods and services produced by the mangrove forest
- Specification and valuation of management alternatives assuming sustainability
- Assessment of the changes in these values should sustainability conditions fail
- Conclusions and recommendations

The Pagbilao Mangroves

The municipality of Pagbilao is located in the southern part of Quezon Province on the island of Luzon, the Philippines. It has an area of 15,820 ha, a population of 41,635 (1990) and an annual population growth rate of 2.77%. The original area of mangroves in Pagbilao is not known but may be deduced from the existing mangrove area and brackish water fishponds. In 1984 the total area of mangrove forest was around 693 ha. Of this, 396 ha were within public forest lands while 297 ha were owned privately. Today, what remains of the public forest land is the Pagbilao mangrove forest comprising 111 ha experimental forest under the jurisdiction of the Department of Environment and Natural Resources. The legal basis of the experimental forest is Presidential proclamations 2151 and 2152 which, in 1981, declared certain islands and/or parts of the country to be wilderness areas. These laws withdrew much of the remaining stands of mangrove from entry, sale, settlement and other forms of disposition, for the main purpose of preserving these ecosystems.

Figure 1 shows Pagbilao Bay. The island of Pagbilao Grande and coral reefs separate the bay from the larger Tayabas Bay. Tayabas Bay, including Pagbilao Bay, is listed among the most seriously threatened wetlands in Asia (Scott and Poole, 1989). The Pagbilao mangroves occupy the delta of the Palsabangan River and are almost surrounded by fishponds. The forest is second growth with an average age of 20 years. It has the largest number of true mangrove species of any stand in the Philippines - its 19 species comprises 56% of all mangroves. In terms of the number of tree species, associates and variations in topography and substrate, it is also the most diverse (NRMC, 1980).

Wildlife populations, particularly of the larger vertebrates, are probably somewhat reduced due to the small remaining mangrove area. Shore birds are the most apparent wildlife species: around 20 species have been recorded feeding in drained and disused fishponds, on mudflats at low tide, or roosting in the mangroves at high tide. Piscivores, such as kingfishers, are common and also supplement their diet, at considerable risk, with fish from the fishponds. The mangroves are a crucial stepping stone in bird migration paths through the Philippines, eg, the Brahminy kite (*Haliastur indus*). Their loss could be expected to cause increased stress and thereby mortality in these populations (Ong, pers. comm.). Few mammal populations remain: the endangered Philippine monkey, *Macaca fascicularis*, would once have inhabited the mangrove forests. Bat populations are present and contribute to the local economy through the collection of their guano, while marine mammals (dolphins and small cetaceans) have also been recorded.

Pagbilao Bay, with its mangroves and coral reefs, is one of the richest, natural marine areas in southern Luzon. Pinto (1987) records 128 species of fish belonging to 54 families from the mangroves alone. Crustaceans (such as prawns and crabs) and molluscs (especially gastropods) are also abundant. Catch data show that a number of fish species were represented by juveniles of typically offshore species such as snappers (*Lutjanus spp*) and groupers (serranids).

Traditionally, the mangroves have been exploited by local communities for minor mangrove products such as vines (handicrafts), gastropods and crabs (food), *Nipa* leaves and wood,

(construction), and plants and fungi (medicines). In the 1970s, however, they were cut for
Figure 1 The Pagbilao Region

commercial fuelwood and charcoal - a major cause of degradation. These activities (with the exception of shell and crab collection) have been prohibited since 1981, although illegal cutting of pole-sized trees is still evident (Carandang and Padilla, 1996a).

Fishpond development occurred primarily during the 1980s on sites where the mangrove cover had been degraded. Mangrove strips were maintained to stabilise the dikes and embankments surrounding the ponds. Aquaculture in the study area is exclusively monoculture of milkfish (*Chanos chanos*) by extensive or semi-intensive means (Figure 2). Fishponds are owned by wealthy individuals (a general and an ambassador own fishponds in the study area) who neither live in the municipality nor employ local residents to manage them.

Figure 2. Fishponds near the Pagbilao mangrove forest

There is a trend in the Philippines towards more intensive aquaculture - higher stocking density, more frequent cropping, use of artificial feeds, fertilisers and pesticides (Padilla and Tanael, 1996). Surpluses and wastes from the ponds are released into the nearby aquatic environment and so may enter the mangrove ecosystem. Soils under mangroves are often acidic and, since acidic soils are not suitable for aquaculture, lime may be applied during construction and/or preparation of ponds for stocking. This may lead to the discharge of very alkaline effluents into the aquatic and mangrove environments.

The coastal villages of Pagbilao are dependent on the ecosystem's support of fishery resources which includes mud crabs and gastropods (foun1`d in and near the mangroves), marine crabs, fish and prawns (taken from the bay). Commercial fishing using trawls is prohibited in the bay so artisanal techniques are used, including corrals, traps, bottom set gill nets, and hooks and lines.

Environmental Functions of Mangroves

The purpose of this section is to define and elaborate on the concept of environmental function and hence to specify the environmental functions of the Pagbilao mangroves. A variety of terms, such as functions, uses, attributes, products, and amenities, have been used to describe what the natural environment contributes to human societies in order to attribute an anthropocentric perspective to ecology. These terms have been applied both to specify and to classify the full range of ecological values for inclusion in management deliberations. The term 'environmental function' is used here. Environmental function has been defined as the provision of environmental goods and/or services by the natural environment for human use (eg. Braat et al., 1979; de Groot, 1992). De Groot may also be credited with giving the term form by devising a lucid terminology and classification of functions (Figure 3). A total of 37 functions grouped into four categories - regulation, carrier, production and information - are identified.

Mangroves perform nearly all of these functions. However, there is a high degree of interaction among them. For example, all of the production functions are ultimately dependent on the regulation functions 'fixation of solar energy and biomass production', 'storage and recycling of organic matter' and 'storage and recycling of nutrients'. The 'storage and recycling of wastes and surpluses' by mangrove ecosystems also contributes to the 'regulation of the chemical composition of the oceans'. 'Fixation of solar energy and biomass production' also contributes to the 'regulation of the chemical composition of the atmosphere' and also to the 'regulation of local and global climate'. While the long list of environmental functions supports the argument that mangroves are valuable, interdependencies among functions lead to complications and ultimately to confusion. Communication is more effective if the message is simple. Further, it is legitimate to ask why two or more functions should be specified if the ultimate result is only one good or service.

The following definition of 'environmental function' has been adopted:

> ***a set of ecological processes responsible for the provision of an environmental good or service for human use.***

The main feature of such a definition is the one-on-one match between environmental function and good/service. Further, identification of environmental functions is driven by specification of the goods or services produced. This adds weight to the anthropocentric perspective for ecologists, as well as encouraging economists to take more consideration of ecosystems.

Goods and services from mangrove ecosystems

This section discusses the range of environmental goods and services provided by mangrove ecosystems as a first step towards identifying the environmental functions of the Pagbilao mangroves (following section). The discussion is based on IUCN (1983), Fisilier (1990), James (1991a & b), Ruitenbeek (1992), Groombridge (1992) and Hirsch and Mauser (1992).

Figure 3: Functions of the natural environment (adapted from de Groot, 1992)

Food and beverages from mangrove ecosystems include fish, crustaceans, shellfish, sea cucumbers, other invertebrates, wildlife, honey, condiments, vegetables, tea substitutes, sugar, alcohol, cooking oil, vinegar and fermented drinks. Traditional medicines may also be derived from (plant, fungal, etc.) species. Fish and crustaceans are caught or grown in ponds located within the mangrove ecosystem. Mangroves may also provide fodder for livestock during the dry season. Mangrove ecosystems also supply raw materials: wood, leaves, *Nipa* shingles and tannins are used in building and construction. Tannins are also used in the manufacture of textiles for clothing and household fabrics. Raw materials for industrial purposes include timber and pulp/chipwood from commercial forestry operations and products from plantations of *Nipa fruticans* which is used to make alcohol for biochemical industries. Mangroves supply fuel and energy products in firewood and the manufacture of charcoal. Juvenile fish and shellfish suitable for (aqua)cultivation may be captured in mangrove ecosystems. Mangrove propagules may be collected, reared in nurseries then transplanted in (government-sponsored) reafforestation and afforestation programmes[1]. Ornamental resources, especially feathers and flowers, may also be derived from mangrove ecosystems.

Species taken from non-mangrove environments, in particular offshore fish and shellfish, may still constitute an environmental good of mangrove ecosystems. Mangrove ecosystems are widely held to be primary nursery areas for commercially important species (eg, MacNae, 1974; Christensen 1982; WRI and IUCN, 1986) and may contribute to offshore productivity via the outwelling of detritus (eg,. Carter, 1988). These paradigms have been questioned in recent years (eg. Ong, 1984 in Fisilier, 1990; Robertson and Duke, 1987; Parrish, 1989; and Thollot et al., 1991). It would appear that the picture is much more complicated: the nursery function may be different for different species; some mangroves act more as a sink rather than as a source of detritus; considerable interaction occurs among mangroves and nearby sea grass beds, coral reefs and mud flats.

Mangroves stand anchored in inter-tidal and supra-tidal substrates which are frequently waterlogged and anoxic. The problem of supplying air to the roots is solved by above-ground root systems (see Figures 4 and 5) which are an essential element of this ecosystem's physical structure. These root systems retard water flow, which leads to a number of environmental services. The quiet environment not only encourages sediments to settle but also inhibits their resuspension. Stabilisation of sediments provides protection to shorelines and associated shore-based activities, and can even lead to progradation and land gains. Further, the resistance which mangroves offer to water flow is particularly important during extreme weather events such as cyclones, typhoons and hurricanes. Mangrove ecosystems mitigate against flooding and flood damage by dissipating the energy of floodwaters.

Mangrove ecosystems function as a sink. Sedimentary processes as well as uptake by organisms filter through-flowing waters, incorporating extracted substances in the sediments and/or in the ecosystem’s biomass. Substances may derive from natural sources as well as various human activities such as agriculture (fertiliser and pesticide surpluses), industry (industrial wastes) and settlements (sewage). Consequently mangrove ecosystems may perform a waste disposal service. The location of fishponds in or adjacent to mangrove

[1]

ecosystems is, in part, dependent on this service. Mangroves are also a sink for carbon dioxide, and so help mitigate against the Greenhouse Effect.

Figure 4. Mangroves on the coastal edge of the Pagbilao mangrove forest

Interest in species found in mangrove ecosystems may be direct (eg, as a source of food) or indirect. Indirect interest tends to stem from a general appreciation of life and the desire for it to be available for future generations. These interests may be expressed passively or actively (ecotourism). Specific aspects within this biodiversity issue include endangered species, migratory species and species with potential commercial value (eg, to the pharmaceutical industry). Ecotourism linked to migratory species may not be in the vicinity of the mangrove ecosystems at all, and may even occur in another country.

Mangrove ecosystems also provide the space and a suitable substrate for human activities. Human settlements may be located within or in the vicinity of mangroves and may be populated by indigenous peoples with subsistence lifestyles dependent on the ecosystem. Mangroves also provide space for cultivation. Aquaculture, rice cultivation and *Nipa* palm plantations may be located in or adjacent to mangrove ecosystems. Recreation and tourism are not activities that spring to mind when considering mangroves, but ecotourism associated with mangroves is developing. Legislation may be enacted to give protection to mangrove ecosystems from (over)use and development.

Figure 5. Growth forms of the mangrove species *Rhizophora* and *Avicennia*

Mangroves provide services which are associated with knowledge. The knowledge that mangrove ecosystems and associated species exist provides an aesthetic service to some individuals. Others acquire spiritual and religious, or cultural and artistic inspiration. This is particularly the case for indigenous populations. Heritage values as well as scientific and educational information may also be derived. Finally, mangrove ecosystems may provide disservices, such as facilitating the breeding of malaria-carrying mosquitoes.

Environmental functions of the Pagbilao mangroves

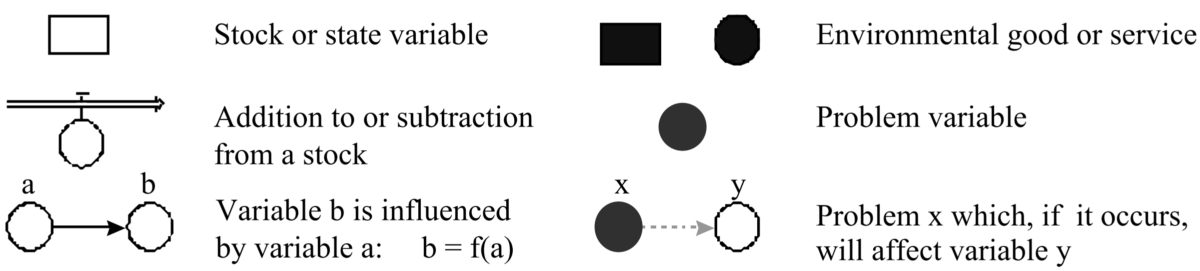
Table 1 identifies a diversity of environmental goods and services provided by the Pagbilao mangroves (a subset of those discussed in the previous section), the environmental functions and ecological processes involved in their provision, and current and potential users of the natural mangrove forest. The terminology of de Groot (1992) is used with some modification. The production of water (for use by fishponds) is, for the sake of simplicity, accredited to the mangroves. Technically it is a product of the environment which mangroves occupy. No disservices are identified and malaria does not occur in the study area.

Table 1. Environmental functions of the Pagbilao mangroves

Feedbacks and Linkages in Mangrove Use

Table 1 shows that some ecological processes are common to more than one environmental function, clearly indicating the interconnectedness within the ecosystem. Should common processes be compromised, the repercussions could be felt over a wide range of users. Evaluation of alternative management strategies should take into account this wider picture of economic-ecological interaction. The systems diagrams presented in this section offer such an integrated approach. The meaning of the various symbols is shown in Figure 6. The diagrams make use of the basic building blocks of systems analysis, viz. stocks, flows and other variables. Added to these are environmental goods and services and problem variables (see Figure 6).

Figure 6. Explanation of symbols used.



The systems diagrams are presented in Figures 8-12; Figure 7 shows how the diagrams are linked. The quality of mangrove cover drives the ecological processes (Figure 8) which control the environmental functions and so the supply of environmental goods and services (Figures 9 and 10). Use of these goods and services contributes value to the users (Figures 11 and 12). An environmental 'problem' develops with overuse where demand for any good or service exceeds its supply. A problem may trigger feedbacks within the ecosystem, or generate costs via linkages between the ecological and the economic systems.

Aggregate land use and ecological processes

Two quality categories for mangrove cover- good and degraded - are identified in Figure 8, with degradation and regrowth generating dynamics between them. Mangroves are removed with fishpond development; historically, this has concentrated on degraded sites. Current information on the profitability of fish farming suggests that the costs incurred in removing mangroves no longer constrain pond development, with the result that fishpond development on sites with good mangrove cover is now possible.

Figure 7. Structure of the systems diagrams

Figure 8: Aggregate dynamics and ecological processes

It is assumed that the better the mangrove cover, the better the performance of ecological processes and hence of environmental functions. The quality of mangrove cover has a direct influence on two key variables - productivity and physical structure - which directly affect other ecological processes. The variable ‘productivity’ is an aggregate of stocks and flows associated with the fixation of carbon and the storage and recycling of carbon and nutrients. Mangrove ecosystems are believed to be highly productive (eg, WRI and IUCN, 1986). ‘Productivity’ influences two ecological processes. Firstly, mangrove ecosystems offer a habitat with abundant food for temporary residents. Secondly, by extracting substances from through-flowing waters and incorporating them in biomass, mangrove ecosystems serve to process and recycle wastes and surpluses from adjacent fishponds.

The physical structure of mangroves is largely determined by their above-ground root systems which contributes to four ecological processes. The quiet environment contributes to habitat, particularly for juvenile aquatic species. The exposure of through-flowing waters to organisms fixed onto the roots assists in the recycling of wastes. The retardation of water flow, as well as the roots themselves, facilitate sediment control. The physical structure also mitigates against flooding. Three problem variables are also shown in Figure 8 - these are defined in Figures 9 and 10. Degradation will be stimulated should these environmental problems occur. Poor water quality also has a direct negative effect on nursery/migration habitat.

The figure implies a smooth transition between all combinations of good and degraded mangrove cover and fishpond development, as well as essentially linear relationships between cover and ecological processes. The real possibility of irreversibilities or discontinuities has not been considered. A key question here is: what is the minimum forest size which could maintain a viable ecosystem? In the absence of information on this point, it is assumed that the current stand is capable of maintaining itself. If such an assumption was unrealistic, then preservation of the Pagbilao mangroves would not be a serious management option.

Production of environmental goods and services

Figures 9 and 10 describe the production of environmental goods and services by the Pagbilao mangroves. The figures use a common format moving from left to right: - ecological process, environmental function, environmental good or service, and environmental problem. Environmental functions and the goods and services they provide are presented as stock-and-flow combinations. The production of environmental goods is straightforward being, in most cases, based on simple population dynamics with harvesting. No distinction is made between the production of wood for construction purposes or for fuel and energy purposes. Over-extraction of environmental goods leads to three problems which, should they occur, trigger costs for users by requiring greater harvesting effort (Figure 11). ‘Over-cut’ also feeds back to Figure 8 by stimulating ecosystem degradation.

Figure 9. Production of environmental goods by the Pagbilao mangroves

Figure 10. Provision of environmental services by the Pagbilao mangroves

The products of fishponds are not environmental goods and so do not appear in Figure 9. While they may be species, they are still economic goods totally dependent on human inputs; environmental goods are dependent on ecological/environmental processes. A fish farm is a fish factory, no different from a power plant occupying space once covered by ecosystems and using water in the production of a good.

Ecological processes in the mangrove ecosystem may affect the structure of waterways, but beyond this they have little influence on water volumes and flows. Water is used to flush fishponds which also releases contaminated water to the environment. Some portion of these wastes and surpluses enters the mangrove ecosystem where they may be taken up by organisms. The problem variable 'poor water quality' develops if the waste load exceeds the system's capacity for removal. Poor water quality feeds back to Figure 8 by stimulating degradation and adversely affecting habitat. It also triggers costs for aquaculture by killing or retarding the growth of the cultured stock (Figures 11 and 12). Chemically persistent pesticides, antibiotics, etc. may accumulate in sediments, have direct toxic effects on species, and/or bioaccumulate in food chains. This may lead to adverse effects on biodiversity.

The services 'shoreline protection', 'flood mitigation' and 'biodiversity' are treated similarly. It is assumed that there is a capacity for supplying these services as a result of the quality of mangrove cover. This capacity is represented by a stock. Changes in the quality of cover filters through various ecological processes to cause a change in this capacity. The environmental problems 'sediment instability' and 'flooding' occur if the quality of mangrove cover declines such that insufficient capacity in relation to conditions in the bay remains. Both problems are linked to economic consequences (Figures 11 and 12) while sediment instability also feeds back to stimulate ecosystem degradation (Figure 8). No problem variable is associated with biodiversity. Feedbacks from a decline in biodiversity are uncertain, probably long term, and so have been ignored. Rather biodiversity is viewed as the ultimate indicator of ecosystem quality. Its decline does not trigger costs, merely a reduction in the values derived from this service.

The information content of the ecosystem is assumed to be related directly to the quality of mangrove cover and the performance of ecological processes, as well as subject to changes in cover and performance. The service provided is knowledge, a subset of the total information contained. No problem variable is identified, essentially for the same reasons as with a decline in biodiversity.

Value of goods and services provided by the mangrove forest

Figures 11 and 12 attempt to capture environmental-economic aspects of using the Pagbilao mangroves. Nine sectors are identified. The approach taken is to imply a net value per sector but considering only 'environmental' benefits and costs. The figures show an annual value derived from using environmental goods and services (flows) accumulating in a net value per sector (stocks). The catch of fish, crabs and shellfish contributes value to the artisanal fisheries. Mud crabs caught on-site comprise about 95% of the value of fisheries. Various goods, mainly for medicines and construction purposes, may be taken by locals from the mangrove ecosystem and so contribute to the value of the subsistence forestry sector. Should the problem variables ‘overfishing’, ‘overcut’ and ‘overuse biotic’ be triggered, costs to these two sectors will rise with increased effort required to harvest these environmental goods.

Figure 11. Values of environmental goods by the Pagbilao mangroves

Figure 12. Values of environmental services by the Pagbilao mangroves

Aquaculture appears in both figures, its activities split into 'aquaculture - fish production' emphasises environmental goods, and 'aquaculture -waste management', which emphasises environmental services. Value accruing to this sector is a function of the area of fishponds (currently zero), water used to flush the ponds, wood used in and around the ponds, and costs avoided by releasing contaminated water into the ecosystem. Costs are incurred should the mangroves be overused as a source of wood, the water quality decline and the stock be killed or its growth retarded, the ponds be flooded and the stock escape (this occurred during the typhoon in November 1995), and/or should the dikes enclosing the ponds be breached, resulting in the escape of the stock and the need to reconstruct the ponds.

The mangrove nursery derives value from the collection of mangrove propagules. It is assumed in the diagrams that sufficient propagules are available. Commercial forestry derives value from cut wood. Costs are incurred should the problem variable 'overcut' be triggered.

The shoreline protection and flood mitigation services of mangrove ecosystems help governments and private individuals to avoid the costs of constructing, say, dikes to limit storm and erosion damage. Should the frequency and/or severity of flooding increase or erosion of the shoreline occur, the damage control sector would incur costs: repair of existing infrastructure, investment in new infrastructure, and emergency costs if the local population is endangered by extreme weather events. Biodiversity provides an annual value to two sectors, ecotourism and existence value. Migratory bird species which use the Pagbilao mangroves may contribute to ecotourism in, say, Australia. The knowledge gained from the information content of the ecosystem contributes value to the scientific and educational community.

Evaluation of Management Alternatives

The current management strategy is to preserve the Pagbilao mangrove forest, allowing only the cutting of mangrove branches for fuel wood and poles, and the collection of resident fish, crabs and gastropods. However there is constant pressure to convert part or all of the ecosystem to fishponds - one attempt to develop a fishpond without formal approval is now under litigation. An evaluation of the different management alternatives for the site of the forest follows the following steps:

- specification of management alternatives;
- assessment of goods and services produced for all management alternatives;
- valuation of goods and services produced for all management alternatives; and,
- evaluation of management alternatives.

A comparison of preservation with other management alternatives puts the costs and benefits of preservation into perspective and provides insight into the pressures for change to other types of use. All alternatives involve management regimes that may be considered sustainable under certain conditions. The costs of unsustainability, are analysed in the next section.

Management alternatives

Eight management alternatives have been formulated and are described below. The conditions under which each regime may be considered sustainable are also specified. A condition for all alternatives is that poaching is effectively prevented.

1. Preservation

Extraction of forest products (wood, *Nipa* shingles, biotic resources for medicines etc.) is not allowed, while the gathering of gastropods and crabs from the ecosystem is. Based on past recovery of the ecosystem under its current management regime, it is reasonable to assume that the ecosystem is capable of further recovery under this alternative. This alternative is essentially a continuation of the *status quo* but with effective prevention of poaching.

2. Subsistence forestry

This management alternative recognises the dependence of coastal communities on the mangroves for forest products such as fuel wood, charcoal and poles (timber) for fences and posts. Management of the forest would be in the hands of the communities themselves. To sustain the benefits derived from the mangroves, a maximum allowable cut must be imposed and held constant despite projected increases in the demand for forest products. This alternative is sustainable under the following four conditions:

- the maximum allowable cut takes into account system-wide effects of use;
- since the maximum allowable cut is less than current estimated demand for forest products, the shortfall can and will be met by increased imports from mountain areas;
- information on how the allowed cut should best be taken can be communicated to and implemented by the forest users, and

- entry into this sector is controlled.

3. Commercial forestry

This alternative provides for exploitation of the mangroves by commercial forestry allowing for a specified commercial harvested volume. High value products are to be harvested, primarily timber with incidental fuel wood from tree branches. Various techniques will be applied to encourage regeneration of the forest. Associated sustainability conditions are: the maximum allowable accounts for system-wide effects of use; and, information on how the allowed cut should best be taken can be communicated to and implemented by the foresters.

The following alternatives incorporate aquaculture to varying degrees. A condition for all of these is the retention of a mangrove strip (buffer zone) of at least 50 meters between ponds and the sea, and at least 20 meters between ponds and waterways. This conforms to current requirements for pond development. It is estimated that the buffer zones will limit storm damage to loss of the stock once every five years on average. Exploitation of this buffer zone will not be permitted.

4. Aqua-silviculture

Excluding the buffer zone, approximately one-third of the mangroves will be converted to fishponds. The culturing technique will be based on the semi-intensive monoculture of milkfish. The remaining mangroves will be contained within the ponds. Litter falling from the mangroves will be captured by the ponds in the hope that this will reduce dependency on artificial feeds. The forest will be harvested sustainably by the fishpond owners for their own needs but may also supplement incomes. The following three sustainability conditions must be met: the buffer zone is sufficient for shoreline stabilisation and flood mitigation; the buffer zone is not exploited; and, wastes released by the ponds into the nearby environment do not overload the system's capacity for self-purification to maintain good water quality.

5. Semi-intensive aquaculture

This alternative converts the forest to fishponds and their water distribution system, with the only remaining mangroves in the buffer zones. Ponds will be stocked with milkfish at around 6,000 fingerlings/hectare/crop and managed using semi-intensive techniques. Sustainability conditions are the same as for Aqua-silviculture (4).

6. Intensive aquaculture

This alternative also converts the mangrove stand to fishponds, but management of the ponds is on a more intensive basis (higher cropping densities, more frequent cropping and greater use of food supplements and chemicals). The recommended intensive technology is alternation of intensive prawn farming with extensive or semi-intensive milkfish farming. Sustainability conditions are the same as for Aqua-silviculture.

7. Commercial forestry/intensive aquaculture

This alternative is a mix of alternatives 3 and 6. Excluding the buffer zones, approximately one third of the mangroves will be converted to fishponds for intensive aquaculture and the remainder will be exploited by commercial forestry. The two activities are separate. Sustainability conditions from alternatives 3 and 6 apply.

8. Subsistence forestry/intensive aquaculture

This alternative is the same as alternative 7 except that the remaining forest, excluding the buffer zones, is exploited sustainably for subsistence forestry products. Sustainability conditions from alternatives 2 and 6 apply.

Effects on goods and services

System diagrams as presented in Section 4 were used to identify the effects which each management alternative would have on the production of goods and services. Field surveys were then undertaken to assess current production and changes in production resulting from alternative management regimes. The effects on shore protection, biodiversity and ecotourism linked to the different alternatives could not be quantified. However, this information was provided by experts from forestry, marine biology and zoology (Carandang, Guarin, Ong 1996; see also Janssen 1992). Table 2 shows the results. Consumption or negative production could occur if an ecosystem drained resources from other systems, for example through export of pollutants or import of clean water. This is not the case for the study site.

Table 2: Annual production of goods and provision of services under different management alternatives.

	Unit	1	2	3	4	5	6	7	8
Goods									
Pond water	---/+++	0	0	0	++	+++	+++	++	++
Bay catch	kg/ha/y	1264	1230	1230	950	63	63	189	189
Residential catch	crabs/y	714	694	694	536	71	71	178	178
Other biotic	---/+++	0	+++	+++	+	+	+	+	++
Propagules	---/+++	+++	+++	+++	0	0	0	+	+
Commercial wood	m^3/y	0	0	317	176	0	0	169	0
Subsistence wood	m^3/y	0	307	0	0	0	0	0	170
Nipa shingles	‘000/y	0	45	45	0	0	0	23	23
Fishponds: milkfish	tons/y	0	0	0	161	537	59	22	22
Fishponds: prawns	tons/y	0	0	0	0	0	158	58	58
Services									
Wastewater disposal	tons/year	0	0	0	21	41	100	50	50
Shoreline protection	---/+++	+++	+++	+++	++	+	+	++	++
Flood mitigation	---/+++	+++	+++	+++	++	+	+	++	++
Biodiversity	---/+++	+++	++	+	+	0	0	+	+
Knowledge	---/+++	+++	++	+	+	0	0	+	+

1. Preservation
2. Subsistence forestry
3. Commercial forestry
4. Aqua-silviculture
5. Semi-intensive aquaculture
6. Intensive aquaculture
7. Commercial forestry/intensive aquaculture
8. Subsistence forestry/intensive aquaculture

+++ large production
++ moderate production
+ small production
0 no production

Production of goods

Resident and transient fish species were sampled to assess fisheries productivity of the mangrove reserve. The fisheries component of this study (Ong and Padilla 1996) also updated information from previous, and more thorough studies (eg, de la Paz and Aragones 1985; Pinto 1985 and 1988; Fortes 1994). The experimental forest supports both on-site (resident species) and off-site (transient species) fisheries. The estimation of sustainable harvest of fishery resources presented difficulties as the fisheries surveys for this study, as well as previous studies, did not cover stock assessment. Simplifying assumptions were made to arrive at some measure of abundance and productivity. The results show that the experimental forest supports a small on-site fishery and contributes minimally to off-site fisheries. Use of a production function would have provided a more precise approach to assess the impacts of the management alternatives on the value of off-site fisheries. However, this was precluded by the limited knowledge on the complex interactions involved and the total lack of data on stock size over time (Spaninks and van Beukering 1997).

Fuel wood, timber and *Nipa* shingles are the primary forest products derived from the Pagbilao mangrove reserve. Subsistence forestry yields goods demanded by coastal communities, mostly fuel wood, charcoal and poles (timber) for fences and posts. The quantification and valuation of goods and services proceeded from field surveys of the mangrove reserve in 1995. Three zones or ecotones were identified: landward, middleward and seaward. Sample plots were established in each ecotone and tree density, tree dimensions and subsequently wood volume were measured or computed. Litter traps were set to estimate litter fall and to determine nutrient content. Projected timber yield was estimated over time using an empirical equation for the Philippines with age of stand and site index as explanatory variables. Subsistence forestry is estimated to produce about 262 m^3 of wood products compared to 272 m^3 per year by commercial forestry; commercial forestry is therefore the more efficient (Carandang and Padilla, 1996).

The performance of aquaculture ponds converted from mangroves was also assessed (Padilla and Tanael 1996a and b). Several studies were compared to assess the long-term prospects of aquaculture operations in the mangrove reserve. The primary objective was to identify the appropriate (sustainable) aquaculture technology and the corresponding production levels. Conversion of the mangrove forest to fishponds results in high production levels. For Semi-intensive aquaculture production was estimated to exceed 597 tons/year of milkfish; for Intensive aquaculture of prawns alternating with extensive culture of milkfish, estimates of 66 tons/year of milkfish combined with 175 tons of prawns were derived (Padilla and Tanael, 1996a and b).

Production of services

Waste water disposal is an environmental service used only by aquaculture. Padilla and Tanael (1996a and b) were able to quantify use of this service for the various aquaculture alternatives. Intensive aquaculture is the highest user due to higher stocking rates and the use of artificial feeds, pesticides and fertilisers. For non-aquaculture alternatives it is assumed that no use is being made of the waste processing capacity of the mangrove forest. Use of the remaining services is estimated qualitatively. While the buffer zones are intended to secure the coastal plain from erosion and flooding, this would still be less than that of an intact ecosystem, or of one which is only two-thirds of its original size. Biodiversity and knowledge services are most abundant in the Preservation alternative (1) and non-existent for Semi-intensive and Intensive aquaculture (5 and 6). Of the remaining alternatives, subsistence forestry, with its softer intervention into the ecosystem, is considered to perform best with regards to these services.

Valuation of goods and services

Market prices and shadow prices of substitutes were used to value goods. Market prices of fish observed at local markets during the field surveys were used to value fisheries. It is estimated that 87.75% of the landed price of fish covers the costs of harvesting, the remainder is the value of the fish in-situ (NSCB 1996). The use value of the forest products derived from the mangroves by subsistence forestry is net of gathering cost. When households are denied access to mangrove forest resources, the shadow price attached to the forest products is equivalent to the cost they incur in obtaining alternative products. Such a cost is equal to the market price of the alternative product plus the transport cost from the market to the point of use. Shadow prices for fuelwood and other goods not traded on the market were linked to the cheapest substitute. For commercial forestry net value is calculated using market prices of the timber products less the costs of transport, extraction and related costs incurred in managing the forest. Net value of aquaculture is calculated using data on production, market prices and operating costs of existing fishponds in the vicinity of the study site.

Net value of the management alternatives can be estimated using these results and is shown in Table 3. In this table values are combined to show the values produced according to economic sectors in the local economy: bay and residential catch are combined into fisheries, *Nipa* is included in subsistence and commercial forestry, and milkfish and prawns are combined into aquaculture. Net values linked to other biotic resources and propagules are considered marginal and therefore ignored. Values shown are annual values for the entire study area. Since alternatives are assumed to be sustainable, the time horizon can be assumed to be indefinite. With regard to aquaculture, the long life of ponds in the vicinity, some around 40 years old, lends support to this assumption. Development costs and other capital costs are valued according to the borrowing rate for capital in real terms. Typhoon damage through flooding of the ponds or breaching of the dikes is included as a ten percent reduction of the annual harvest, based on two crops per year and loss of one crop once every five years.

Table 3. Net annual value of goods and services under different management alternatives.

	Unit	1	2	3	4	5	6	7	8
Goods									
Fisheries	’000 pesos	165	161	161	124	8	8	40	40
Subsistence forestry	’000 pesos	0	349	0	0	0	0	0	189
Commercial forestry	’000 pesos	0	0	416	218	0	0	229	0
Aquaculture - fish	’000 pesos	0	0	0	5648	18801	13577	4992	4992
Mangrove nursery	0/+++	+	+	+	0	0	0	0	0
Total goods	’000 pesos	165	510	577	5990	18809	13585	5261	5221
Services									
Aquaculture - waste	0/+++	0	0	0	+	++	+++	++	++
Damage control	0/+++	+++	+++	+++	++	+	+	++	++
Ecotourism	0/+++	+++	++	0	0	0	0	0	+
Existence value	0/+++	+++	++	++	+	0	0	+	+
Information value	0/+++	+++	+++	++	+	0	0	+	+
Total services	0/+++	+++	+++	++	+	+	+	+	+

1 Preservation	+++	large contribution to value
2 Subsistence forestry	++	moderate contribution to value
3 Commercial forestry	+	small contribution to value
4 Aqua-silviculture	0	no contribution to value
5 Semi-intensive aquaculture		
6 Intensive aquaculture		
7 Commercial forestry/intensive aquaculture		
8 Subsistence forestry/intensive aquaculture		

For the five alternatives which permit harvesting of forest products, the highest value is generated by Commercial forestry (3). Aquaculture alternatives perform better than Forestry (2/3) and Preservation (1) in terms of the value of goods produced. Semi-intensive aquaculture (5) performs better than Intensive aquaculture (6) due to the high development costs linked to the latter and to constraints set by sustainable management of the ponds. However, the performance of both alternatives is very sensitive to changes in prices. Milkfish are produced for the local market and their price level is relatively stable. The price of prawns is determined on the world market and shows strong fluctuations. In this study a price of 185 pesos/kg is used for prawns. Should this price increase above 214 pesos/kg the value of goods produced by Intensive aquaculture will be higher than those produced by Semi-intensive aquaculture. Aqua-silviculture performs better than the alternatives combining forestry and aquaculture. Note that the mangrove nursery is unlikely to survive the conversion to fish farming.

Services are valued only qualitatively in Table 3 and an attempt is made to aggregate these sources of value. The improvements to the ecosystem which Preservation (1) provides is felt by all users permitted by this alternative. The main gains are felt by damage control (avoided costs), fisheries, the mangrove nursery, and existence and scientific values. No use is made of the ecosystem's capacity to process wastes, and so this service scores a zero. However, such a capacity exists. The total value from services is considered a maximum for this alternative. Subsistence forestry (2) also scores a maximum, even though this alternative scores somewhat lower with regards to ecotourism and existence value sectors: harvesting of forest products is assumed to affect biodiversity adversely. Commercial forestry's (2) aggregate score is lower than alternatives 1 and 2. This alternative precludes contributions to ecotourism as well as reducing biodiversity and information values. As with Subsistence forestry, the forest remains intact and so its capacity to mitigate against flooding and prevent erosion is high.

The aquaculture alternatives (4 to 8) score poorly with the system's capacity to provide services for use. While the waste disposal capacity of the system is used in these alternatives, the buffer zones supply only a minimal capacity for damage control. Where more of the stand is maintained, this capacity is larger. All alternatives, except that including subsistence forestry (8), preclude any contribution to ecotourism. Some existence and information values remain in alternatives where more mangroves than just the buffer zone are retained.

Comparison with other studies

A literature survey was conducted to compare results from the Pagbilao study with other mangrove studies (Spaninks and Beukering, 1997). Table 4 shows the results from this study (last column) compared with results from studies in Thailand, Fiji and Indonesia. To facilitate comparison all results are presented in US$/ha. Please note that these values relate to different years. No data were available to adjust for inflation rates and changes in exchange rates in the different countries. The values for forestry and fisheries are similar to those derived in the other studies. The value of aquaculture is listed as a negative value since this represents the foregone benefits of not converting the forest to fishponds and can therefore be considered as an incremental cost of preservation. The value used by Lal (1990) for purification involves construction of a sewage treatment plant. Since water pollution is not a problem in Pagbilao this value cannot be attributed to waste disposal here.

Table 4. A comparison of net annual benefits of goods and services provided by mangrove forests (all values in US$/ha/year, 1US$=25 pesos).

	Thailand Christensen (1982)	Fiji Lal (1990)	Indonesia Ruitenbeek (1992)	Pagbilao (1996)
Forestry	30	6	67	151
Fisheries	130	100	117	60
Agriculture	165	52		
Aquaculture	-2,106			-7,124
Erosion			3	
Biodiversity			15	
Local uses	230		33	
Waste disposal		5,820		

Ranking of management alternatives

Based on the value of total goods Semi-intensive aquaculture (5) is the most preferred alternative followed by Intensive aquaculture (6). Preservation (1) and also the forestry alternatives (2 and 3) generate substantially less value in terms of goods. Based on total services, however, Preservation (1) and Subsistence forestry rank higher and the aquaculture alternatives much lower.

Because the provision of services could not be valued it proved impossible to calculate total value of the alternatives. This raises the question of whether the value of the services provided by Preservation (1) will be large enough to offset its lower value of goods. The difference in total goods between the two alternatives as shown in Table 3 is more than 18 million pesos, almost US$6,500/ha/year (Table 4). Using the other studies presented in Table 4 to derive a very rough indication of the value of services, the Preservation alternative (1) would seem unlikely to generate total values higher than Semi-intensive aquaculture (5). Therefore, it may be concluded that, on the basis of valuation, Semi-intensive aquaculture (5) is the most preferred alternative.

It is important to note that valuation has its limitations. Distribution of income is a central political issue, especially in developing countries. Benefits from fisheries are received by local, usually poor, fishermen, while benefits from fishponds, due to their high investment costs, accrue to distant, rich investors. Conversion of mangroves to fishponds therefore results in a unfavourable change in income distribution which is not reflected in total value. It also creates areas which are inaccessible to the local population. A second limitation of valuation is that it assumes the possibility of substitution between human and natural capital. This creates serious difficulties if irreversible effects, such as the loss of biodiversity, are to be included.

Costs of Unsustainability

The values of each management alternative were estimated in the previous section. The management alternatives are designed to be sustainable, with sustainability holding under a number of conditions. Failure of these conditions generates costs and/or reductions of benefits. The purpose of this section is to assess what could happen if certain conditions do not hold and the management alternatives fail the sustainability criteria (see also Parks and Bonifaz 1994). Because sustainability is the norm, the effect of failure to meet this norm may be labelled the 'costs of unsustainability'. Four conditions are tested in this section:

- Failure of the buffer zones to mitigate against flooding and stabilising the shore;
- Excessive extraction of wood
- Poaching of wood products cannot be prevented; and,
- Overloading of natural waste management to process and remove wastes and surpluses.

Effects may be traced through Figures 5-9 by linking failure of a condition with the problem variable triggered and subsequent effects on the supply of environmental goods and services. The link between condition and problem variable is presented in Table 5 for each management alternative. Table 6 presents total (monetary) value and effects on the provision of environmental services when all sustainability conditions fail simultaneously. The discussion below explains how this table is derived.

Table 5: Problem variables triggered by failure of management conditions

Condition	1	2 & 3	4	5	6	7 & 8
Failure of buffer zones			instability, flooding	instability, flooding	instability, flooding	instability, flooding
Excessive wood harvest		overcut				overcut
Poaching of wood products	overcut, instability	overcut, instability	instability, flooding	instability, flooding	instability, flooding	overcut, instability, flooding
Overloading of natural waste management			poor water quality	poor water quality	poor water quality, bio-accumulation	poor water quality, bio-accumulation

1 Preservation
2 Subsistence forestry
3 Commercial forestry
4 Aqua-silviculture
5 Semi-intensive aquaculture
6 Intensive aquaculture
7 Commercial forestry/intensive aquaculture
8 Subsistence forestry/intensive aquaculture

Failure of the buffer zones

An essential condition of all alternatives including aquaculture (4-8) is the retention of buffer zones to ensure sediment stability and mitigate against flooding. If buffer zones are inadequate for these purposes, the problem variables 'instability' and 'flooding' will be triggered (Figure 7). 'Instability' stimulates ecosystem degradation (Figure 5) and will lead to the poorer performance of all environmental functions.

Both 'instability' and 'flooding' cause direct costs to users (Figures 8 and 9). The bulk of these costs will be borne by aquaculture which will lose its stock more frequently. Aquaculture alternatives (4, 7 and 8), where more mangrove cover than just the buffer zones is retained, will be less vulnerable to sediment instability and flooding and the impacts of these problems are more likely to remain small-scale. There is the risk with Semi-intensive and Intensive aquaculture (5 and 6) that sediment instability could spread beyond the study site and/or that flood waters could penetrate further inland. Damage would then be incurred by more economic activities, with costs borne by the damage control sector.

Excessive extraction of wood

Management alternatives 2, 3, 7 and 8 are based on the sustainable extraction of forest products. A condition with Subsistence forestry (2 and 8) is that entry into the sector can be controlled so that extraction will not exceed a maximum allowable cut. Local demand for wood products already exceeds this maximum (Carandang and Padilla, 1996) and will only increase with population growth. It is highly unlikely that agreements between government and local communities to limit entry into the subsistence forestry sector will be effective under such pressure, with inevitable over-extraction. Similar controls are required for Commercial forestry (3 and 7) to limit the harvest to a maximum allowable cut. Given the pressure for short-term profit maximisation, this condition is also likely to fail.

Excessive extraction of wood triggers the problem variable 'overcut' (Figure 6) in all alternatives containing forestry. This, in turn, stimulates ecosystem degradation (Figure 5) and poorer performance of environmental functions, with all mangrove users being worse off. The forestry sectors, with a limited duration of activities, will bear the brunt of the costs of unsustainability.

Poaching of wood products

A key condition for sustainable management is the effective prevention of poaching. Under the current management regime, wood is poached by local residents for construction purposes and fuel, and by fishpond managers who use wood for fencing, reinforcing dikes, delivering feeding supplements and for construction purposes. Given the local demand for wood and the difficulties in limiting access to the mangrove ecosystem, it is highly unlikely that poaching can be prevented. Two possible effects of wood poaching are identified.

Firstly, poaching would cause wood harvesting in all forestry alternatives to exceed the maximum allowable cut. It could also lead to a level of illegal wood extraction above the ecosystem's capacity for regeneration within the Preservation(1) alternative, given the growing demand for wood products and their increasing availability within the mangrove ecosystem. The problem variable 'overcut' (Figure 6) would then be triggered. As discussed above, this would stimulate ecosystem-wide degradation (Figure 5) and reduce performance of all environmental functions.

Secondly, poaching will be concentrated in areas of easy access and particularly along the edges of waterways. This may cause bank erosion and even trigger the problem variable 'instability' (Figure 7). 'Instability' has implications for degradation (Figure 5). In alternatives excluding aquaculture, the impacts of poaching are likely to remain localised. However in alternatives incorporating aquaculture poaching could compromise the buffer zones, with impacts and costs which have been discussed above.

Overloading of natural waste management

All alternatives including aquaculture depend on the system's natural capacity to remove and process wastes and surpluses released into the natural environment. Semi-intensive and extensive aquaculture in Pagbilao Bay have not yet overloaded this capacity, although the possibility exists that increasing aquaculture could exceed a threshold, resulting in water quality problems. The likelihood of this is greatest with intensive aquaculture techniques which use high stocking rates, chemicals to control pests and diseases, and feeding supplements.

'Poor water quality' is one of two problem variables which could be triggered (Figure 7). This not only stimulates degradation, but also has direct impacts on the mangrove habitat (Figure 5). Poor water quality results in costs to aquaculture and, if persistent, these activities will become uneconomic. This is most likely for Intensive aquaculture (6) and possible for Semi-intensive aquaculture (5). Alternatives 7 and 8, which comprise some intensive aquaculture could experience periodic problems with water quality; however it is assumed that this would reduce, but not compromise, the profitability of these activities.

The second problem variable, 'bioaccumulation', would be triggered only by intensive aquaculture through the use of chemicals (see Figure 7). Bioaccumulation of persistent micropollutants could have an adverse effect on biodiversity, and so on dependent activities (viz. ecotourism, existence value and information value). However these effects are relevant only for aquaculture/forestry alternatives (7 and 8) since insufficient biodiversity and information remain with Intensive aquaculture (6).

Changes in the ranking of alternatives if all sustainability conditions fail

Failure of the sustainability conditions are not independent events. For example, inadequate enforcement of environmental regulations can result in inadequate buffer zones, excessive extraction, poaching and unauthorised emissions of wastes. Table 6 shows for each good and service the range of expected change in value if all sustainability conditions fail simultaneously.

These ranges are combined with the values of goods and services (Table 3) to calculate the value of total goods and services. The table provides:

a) total goods and services (min) representing the pessimistic end of the ranges (↓,↓↓, ↓↓↓ =-33%, -66%,-100%),

b) total goods and services (max) representing the optimistic end of the ranges (↓,↓↓, ↓↓↓ =-0%, -33%,-66%) and

c) total goods and services (sust) representing sustainable conditions as listed in Table 3.

Table 6: Change in net annual value if all sustainability conditions are violated simultaneously.

	1	2	3	4	5	6	7	8
Goods								
Fisheries	↓	↓	↓	↓↓	↓↓	↓↓	↓↓	↓↓
Subsistence forestry		↓↓						↓↓
Commercial forestry			↓↓				↓↓	
Aquaculture				↓	↓↓↓	↓↓↓	↓↓	↓↓
Mangrove nursery	↓	↓	↓					
A: total goods (min)	111	227	249	4044	3	3	1789	1775
B: total goods (max)	165	395	440	5949	6398	4622	3525	3498
C: total goods (sust)	165	510	577	5990	18809	13585	5261	5221
Services								
Aquaculture					↓↓	↓↓↓	↓	↓
Damage control	↓	↓	↓	↓↓	↓↓↓	↓↓↓	↓↓	↓↓
Ecotourism	↓	↓						↓
Existence value	↓	↓	↓	↓↓			↓↓↓	↓↓↓
Information value	↓	↓	↓	↓↓			↓↓↓	↓↓↓
A: total services (min)	++	++	+	0	0	0	0	0
B: total services (max)	+++	+++	++	+	0	0	0	+
C: total services (sust)	+++	+++	++	+	+	+	+	+

1. Preservation
2. Subsistence forestry
3. Commercial forestry
4. Aqua-silviculture
5. Semi-intensive aquaculture
6. Intensive aquaculture
7. Commercial forestry/intensive aquaculture
8. Subsistence forestry/intensive aquaculture

↓↓↓	large reduction in value (67-100%)
↓↓	moderate reduction in value (33-67%)
↓	small reduction in value (0-33%)
	no reduction in value

From Table 6 it can be concluded that violating the sustainability conditions results in a lose-lose situation where the total value of all alternatives decline. Preservation shows a decline because of ecosystem degradation. The forestry alternatives show a decline in long term wood production combined with a decline in the provision of most services. The aquaculture alternatives face a loss in long term fish production. Although the pattern of changes differs considerably between alternatives, the ranking of alternatives is relatively insensitive to failure of these sustainability conditions. The rankings associated with total goods (max) are the same as the ranking under sustainability, with Semi-intensive (5) at the first position and Preservation (1) at the last. However if the pessimistic values (total goods min) are compared with the ranking under sustainability, Semi-intensive aquaculture (5) and Intensive aquaculture (6) shift to last position. This is the disaster scenario for both alternatives where pollution results in the complete failure of operations. The most likely position between these extremes is difficult to predict. Uncertainty centres on two questions: how much waste can the system manage without water quality declining and at what stage are the effects of declining water quality irreversible? In general, Semi-intensive aquaculture runs fewer risks than Intensive aquaculture, as does partial conversion to aquaculture compared to conversion of the whole mangrove stand.

Conclusions and Recommendations

In this study ecological and economic information are combined to support the evaluation of management alternatives for the Pagbilao mangrove forest. A key problem which ecologists face is the high degree of interconnectedness within and between ecosystems. This makes it difficult to predict what is going to happen let alone understand what is going on. The concept of 'environmental function' is used in combination with systems diagrams to address this problem. System diagrams are used to identify and assess goods and services produced by the ecosystem under different management regimes. These goods and services are then valued to assess the economic efficiency of the management regimes. This final section assesses the usefulness of the concept of environmental function, summarises the results of the study and offers recommendations for further research.

Mangroves are complex systems which provide a variety of goods and services for human use. The high degree of interconnectedness within such ecosystems leads to uncertainty and unpredictability. In particular it means that environmental goods and services are rarely produced independently. The concept of environmental function was used in this study to communicate the environmental values of the Pagbilao mangroves. The interface between environmental supply and societal demand for goods and services from the mangroves could then be detailed. This was effective in demonstrating the complexity of ecosystem performance to non-ecologists, and in particular the multiple interdependencies involved in providing environmental goods and services. Systems diagrams were used to envisage ecosystem performance and to 'think through' what the alternative management options and their associated conditions implied in terms of future supply of mangrove goods and services. In combination with valuation of selected products, the evaluation of alternative management regimes was then based on the integration of ecological and economic information.

This study assessed the conversion of the 110.7 hectares of protected mangrove forest in Pagbilao, Philippines into aquaculture, forestry and combined uses. Considerable effort was invested in data collection and modelling, although the results have to be used with care. This especially holds for those linked to off-site fisheries. It proved to be very difficult to establish a clear link between the size of the mangrove forest and the value of off-site fisheries. A production function approach proved to be unfeasible. Further, most services could not be valued and so could only be included qualitatively. Given these limitations the following may be concluded:

For the Pagbilao mangrove forest Semi-intensive aquaculture is the policy alternative with the highest economic value. If sustainability conditions are not met total values of all alternatives are reduced. However, Semi-intensive aquaculture still produces the largest total value except under extreme conditions.

Environmental services, such as biodiversity, shore protection and flood mitigation, need to be priced very high to attribute Preservation with the highest value. However, if it is accepted that preservation of the mangrove forest is in the interest of the world community, it is unreasonable that the Philippines should pay the price of preservation; the increcemental costs of preservation should be the responsibility of The Global Environmental Facility.

Although biodiversity is considered crucial to the decision to preserve the forest, it proved impossible to put a monetary value on changes in biodiversity. This raises questions regarding the limitations of valuation - is it possible to value irreversible effects such as the loss of life, the loss of ecosystems, the loss of species, the loss of works of art etc. Another crucial issue in the case of Pagbilao is the distribution of wealth. The income from the fish ponds accrues to distant investors, while conversion to fish ponds creates areas inaccessible to the local population. Equity issues cannot be addressed adequately using net value as a decision criterion.

Further research

- Further research on ecological linkages both within mangrove ecosystems as between mangrove and other coastal ecosystems is essential.

- Assessment of production functions between mangroves and mangrove-related products, such as fisheries, can be seen as an extension of these efforts. However, it is questionable whether assessment of production is feasible in applications such as Pagbilao.

- Further research on approaches for valuing environmental services such as biodiversity is necessary. This should include an appraisal of the appropriateness of valuation to support decisions including these types of environmental values.

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